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From **German into English**

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On this day personally appeared before me Elisabeth A. Lucas who, after being duly sworn, deposes and states:

That he is a translator of the **German** and English languages by profession and as such connected with the **LAWYERS' & MERCHANTS' TRANSLATION BUREAU;**

That he is thoroughly conversant with these languages;

That he has carefully made the attached translation from the original document written in the **German** language; and

That the attached translation is a true and correct English version of such original, to the best of his knowledge and belief.

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APR 27 2005

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Force-sensing bearing

Field of the invention

The invention relates to a rolling bearing comprising arranged sensors by means of which the present loading on the rolling bearing can be determined.

US 5,952,578 describes such force-sensing bearings. Figure 10b of this document illustrates how, in the case of a tapered roller bearing, the force (material elongation) measured by the sensors is divided into radial forces and axial forces. The problem of this solution is that the raceway angle has to be constant in order to decompose the forces into radial and axial forces. For rolling bearings comprising curved raceways, such as e.g. deep-groove ball bearings, the method described cannot be employed to determine the axial or radial forces acting on the rolling bearing with sensors arranged opposite the raceways.

Object of the invention

Therefore, the object is to demonstrate a sensor arrangement for rolling bearings comprising curved raceways in the case of which the measured forces can be unambiguously decomposed into axial and radial forces.

Description of the invention

The object is achieved according to the invention by means of the features of claim 1.

The essence of the invention consists in arranging sensors (e.g. strain gauge sensors) on the outer diameter of the outer ring or on the inner diameter of the inner ring, which generate time signals of different length in the event of loading (Hertzian compression) of the rings by the rolling bodies depending on the axial position in the raceways of the rolling bearing. The signals of different length are generated by varying the length of two adjacent conductor track sections of the strain gauge sensor that lie in the circumferential direction. The time signals of different length in the event of loading are thus proportional to the contact angle of the rolling bodies in the raceway of the rolling bearing rings. This arrangement of the strain gauge sensors exploits the effect that, in the case of rolling bearings comprising curved raceways, the rolling bodies move out of the raceway base in the event of a combined radial-axial loading and assume a new equilibrium position outside the raceway base. The higher the axial loading becomes, the further the rolling body moves from the raceway base in the direction of the side area of the rolling bearing. This also results in a shift in the pressure ellipse between rolling bearing ring and rolling body in the axial direction. The

pressure ellipse also leads to a length alteration in the circumferential direction in the material of the rolling bearing ring. The sensors, having different widths in the axial direction, thus detect the length alteration in the material - upon the rolling body rolling through - for different lengths. The length of the loading of a sensor can be converted into radial and axial forces through knowledge of the geometry of the rolling bearing.
Since the loading duration of a sensor is also dependent on the rotational speed of the rolling bearing, the rotational speed is determined by means of the time interval required by two adjacent rolling bodies to load a sensor.
The advantage of claim 3 consists in the fact that commercially available rectangular strain gauge sensors can be used in the case of this arrangement.

Description of the figures

The invention is described with reference to 6 figures.

Figure 1 illustrates a rolling bearing comprising curved raceways (here a deep-groove ball bearing). The rolling body 1 is arranged between the two races 2 and 3. In this illustration, the rolling body is situated precisely in the central position of the rolling bearing. In the event of loading, said rolling body migrates in the axial direction

toward the side area 2a or 2b of the rolling bearing, this depending on the force direction of the axial forces. In this example, the sensors 4 are arranged in a groove 5 on the outer ring 2. The analogous arrangement of the sensors 4 in a groove on the inner ring 3 is not illustrated.

Figures 2 to figure 5 show special sensor arrangements arranged in the groove 4 on the outer ring 2 and/or on the inner ring 3. In order to better discern the arrangement of the sensors, the rolling bearing races are shown unwound in the illustration. The sensors 4 are illustrated in trapezoidal arrangement here in the preferred embodiment of a strain gauge. The conductor track sections of the strain gauge sensor 4a and 4b, respectively, are embodied with different lengths in the axial direction 6. It immediately becomes clear from this illustration that a rolling body which moves out of the raceway base in the axial direction 6 loads the sensors 4 for different lengths (of time). The length of the time signal of a sensor is thus proportional to the angular position of the rolling body 1 in the rolling bearing races 2 or 3. Since the sensors 4 are normally connected up to form Wheatstone bridges, the duration of the output signal of the Wheatstone bridge is thus proportional to the contact angle of the rolling body 1 in the raceway of the rolling bearing races 2 or 3. A preferred embodiment in this case is the arrangement of the strain gauge sensors at a distance in the rolling bearing

race that corresponds to half the distance between two adjacent rolling bodies.

Fig. 2b illustrates the output signals of the Wheatstone bridge for the case where the rolling body rolls through in the region of the short conductor track sections 4a under the strain gauge sensor. The position of the rolling bodies that roll through under the sensors is identified by the arrow 10. The period duration 8a of the signals is correspondingly short.

Fig. 2c illustrates the output signals of the Wheatstone bridge for the case where the rolling body rolls through in a region of the long conductor track sections under the strain gauge sensor. The position of the rolling bodies that roll through under the sensors is identified by the arrow 11. The period duration 8b of the signals is correspondingly long. The period duration is thus proportional to the angular position of the rolling bodies in the raceway given a known rotational speed of the rolling bearing.

In the case of the sensor arrangement in fig. 3, the angular position of the rolling bodies in the raceway is determined by averaging the long and short period durations in the output signal of the Wheatstone bridge. Fig. 3a illustrates the output signal of the Wheatstone bridge. The alternate period duration 8c is identified.

In the case of the sensor arrangements in fig. 4 and 5, the time interval between two adjacent sensors 4c, 4d

becoming loaded is proportional to the angular position of the rolling body 1 in the raceways 2c, 3c of the rolling bearing races 2 or 3. Figures 4 and 5 differ by virtue of differently oriented conductor track sections in the sensors (strain gauge sensors) 4c and 4d. The comparable case with the use of commercially available strain gauge sensors with a right-angled base area is not illustrated.

Fig. 6 illustrates a detail from the rolling bearing race with the sensors 4. The rolling body 1 is depicted in different positions in the raceway. The signal determined by the sensor 4 (of a sensor of the Wheatstone bridge) is represented below the detail from the rolling bearing race. The change in resistance ($\Delta R/R$) in the sensor 4 is plotted on the ordinate of the system of coordinates and time (t) is plotted on the abscissa. The different period duration 8 in dependence on the contact angle of the rolling bodies in the raceway of the rolling bearing races becomes clear in this illustration. The magnitude of the signal 9 is proportional to the loading of the rolling bearing race.

List of reference symbols

1	Rolling body
2	Outer ring
2a, 2b	Side area of the outer ring
2c	Raceway of the outer ring
3	Inner ring
3c	Raceway of the inner ring
4	Sensors
4a, 4b	Conductor tracks of the sensor that have different lengths
4c, 4d	Sensors having the same width
5	Groove in the outer or inner ring
6	Axial direction of the rolling bearing
7	Circumferential direction of the outer or inner ring
8	Period duration of the signal
8a	Short period duration of the signal
8b	Long period duration of the signal
8c	Short and long period duration successively in the signal of the Wheatstone bridge
9	Corresponds to the elongation of the material and is proportional to the magnitude of the loading of the rolling bearing race
10, 11	Position of the rolling bodies that roll through under the sensor